Obstructive Sleep Apnea Syndrome Increases Pedestrian Injury Risk in Children

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Objectives To evaluate pedestrian behavior, including reaction time, impulsivity, risk-taking, attention, and decision-making, in children with obstructive sleep apnea syndrome (OSAS) compared with healthy controls.

Study design Using a case control design, 8- to 16-year-olds (n = 60) with newly diagnosed and untreated OSAS engaged in a virtual reality pedestrian environment. Sixty-one healthy children matched using a yoke-control procedure by age, race, sex, and household income served as controls.

Results Children with OSAS were riskier pedestrians than healthy children of the same age, race, and sex. Children with OSAS waited less time to cross ($P < .01$). The groups did not differ in looking at oncoming traffic or taking longer to decide to cross.

Conclusions Results suggest OSAS may have significant consequences on children's daytime functioning in a critical domain of personal safety, pedestrian skills. Children with OSAS appeared to have greater impulsivity when crossing streets. Results highlight the need for heightened awareness of the consequences of untreated sleep disorders and identify a possible target for pediatric injury prevention. *(J Pediatr 2015;166:109-14)*.

Annually, 5300 American pedestrians are killed and 85 000 others are injured; over one-third of injured pedestrians are children.[1] In middle childhood, about 60% of pedestrian injuries and mortalities occur when the child is crossing a road at or between intersections, typically within one-half of a mile of the child's home.[2-4] Several studies suggest young children regularly negotiate dangerous street environments alone when going to and from school.[2,5-7] Not surprisingly, prevention of pediatric pedestrian injury has been targeted as a national public health priority.[8]

Many factors contribute to unintentional pedestrian injury. Among them are cognitive and temperamental traits of the pedestrian, including reaction time, impulsivity, risk-taking, attention, and decision-making.[9-12] These same characteristics that influence pedestrian safety are negatively influenced by sleepiness, both from sleep deprivation/insufficient sleep and from sleep disorders such as obstructive sleep apnea syndrome (OSAS).[13-18]

OSAS is a common sleep-related breathing disorder, with estimated prevalence of 1%-5% among nonobese children and 25%-40% in obese children.[19,20] Sleep disorders put adults at high risk for human error, mental inefficiency, and injury.[13,14] In adults, OSAS has negative consequences on mood and behavioral regulation and on neurocognitive functioning, including learning, vigilance, attention, memory, problem solving, and visual and motor functioning.[20,21] Adults with OSAS are more likely to have daytime sleepiness resulting in motor vehicle accidents and occupational injury.[14,15]

The effect of OSAS on child safety is less well understood. Emerging evidence suggests sleep disorders such as OSAS may cause significant daytime consequences in children performing basic laboratory tasks requiring cognitive skills such as impulse control, reaction time, memory, attention, decision-making, regulation of risk, and regulation of emotions,[16-18] but little research investigates how pediatric sleep disorders such as OSAS may influence children's safety in applied, real-life settings.

Pedestrian behavior is a highly complex cognitive and perceptual task. A safe pedestrian must simultaneously process several pieces of information, interpret their meaning, and make a decision to cross the street when a safe opportunity arises. These tasks must occur very quickly. Impulse control, attentional processes, memory, and reaction time are critical components of pedestrian safety.[9,12,22] Given cognitive impairments among children with OSAS reported in laboratory tasks,[16-18] children with OSAS may have significant deficits in pedestrian safety. This study examined that possibility. Using an interactive and semi-immersive virtual pedestrian environment, 60 children with OSAS and 61 yoke-matched healthy controls crossed a virtual street several times. We hypothesized children with OSAS would have a greater number of hits or close calls with virtual vehicles compared with healthy children. We further hypothesized that children with OSAS would look at traffic less before crossing, would wait

ADHD	Attention deficit/hyperactivity disorder
BMI	Body mass index
NPSG	Nocturnal polysomnography
OSAS	Obstructive sleep apnea syndrome
PDSS	Pediatric Daytime Sleepiness Scale
VRPE	Virtual reality pedestrian environment

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less time before initiating a cross, would take longer to decide to cross, and would select unsafe traffic gaps more often than healthy control children.

Methods

One hundred twenty-one children participated; 61 of the children were diagnosed with OSAS. Diagnosis and recruitment of that portion of the sample occurred at the Pediatric Sleep Disorders Center at Children's of Alabama. All participating children met International Classification of Sleep Disorders Second Edition diagnostic criteria for OSAS[23] based on diagnostic assessments that included nocturnal polysomnography (NPSG) using Sandman 9.2 technology software (Embla, Broomfield, Colorado) and thorough clinical evaluation from 1 of 2 attending board-certified sleep specialists early in the morning after the overnight NPSG. Standard polysomnography consisted of electroencephalogram, electromyogram, electrooculogram (right, left), arterial oxygen saturation (SaO_2) oximeter pulse wave form, and end-tidal carbon dioxide tension, nasal pressure monitoring, oronasal flow using thermistor, and thoracic and abdominal wall motion. Standard pediatric scoring was used for respiratory events.[24] Diagnosis of OSAS was defined as apnea hypopnea index $\geq$1 per hour.[23]

Exclusion criteria included cognitive or physical disabilities that prevented full participation in the experimental protocol (eg, intellectual disability, blindness, use of a wheelchair); comorbid medical or neurologic conditions; or antipsychotic medication use. No children were excluded for these reasons. One child with OSAS requested withdrawal from the study without explanation and no usable data were available for that child. To verify sleepiness, we sampled level of sleepiness using the Pediatric Daytime Sleepiness Scale (PDSS).[25] Children with OSAS scored high on the scale (M = 17.23, SD = 7.38; mean in validation work 15.3).[25]

Sixty-one healthy children were recruited from the community using a laboratory database of community residents interested in participating in research. Recruitment occurred by searching the database for potential participants who matched children with OSAS by age, sex, race, and average income in the zip code of residence. This strategy, sometimes called yoke-matching, yielded a control sample with demographic characteristics that were quite similar to those in the case sample of children with OSAS. The same exclusion criteria used in the case sample were applied; no children were excluded. We also screened for diagnosed sleep disorder, and no parents reported their child had any. The control sample was adequately alert with a mean PDSS score of 12.03 (SD = 5.10).[25]

Children provided informed assent and caregivers informed consent. Caregivers prohibited caffeine intake for children the morning of the research appointment and were instructed to keep children awake after their routine wake time in either the Pediatric Sleep Disorders Center (children with OSAS) or during the drive to the appointment (healthy controls). Once the family arrived at the appointment and consent processes were completed, children participated in the virtual reality pedestrian environment (VRPE) while caregivers completed demographic questionnaires. The research session lasted approximately 1 hour, and families were compensated for their time. The study protocol was approved by the Institutional Review Board at the University of Alabama at Birmingham.

VRPE

Details of the VRPE, including validation data demonstrating behavior in the virtual world corresponds with behavior in real pedestrian environments among both children and adults are available elsewhere.[10] In that study, construct validity was demonstrated with significant correlations between behavior in the virtual and real worlds among both children and adults. Convergent validity was shown by correlations between parent-reported child temperament and behavior in the virtual world. Internal reliability of various measures of pedestrian safety in the virtual world was demonstrated. Face validity was demonstrated by users' self-reported perception of realism in the virtual world. Additional evidence of the environment's validity comes from several studies showing impaired pedestrian behavior under a variety of conditions and situations among both children and adults.[10,26-32] Taken together, we believe the VRPE offers a valid tool to study children's pedestrian injury risk without exposing children to actual traffic.[10,26-32]

While participating in the virtual environment task, children stood on a wooden simulated curb and viewed the virtual pedestrian environment on 3 consecutive monitors arranged in a semicircle in front of them. Children were immersed in the virtual environment as they watched vehicles pass bidirectionally on the screens and heard environmental and traffic noise through speakers in the room. After deciding it was safe to cross, they stepped off the curb onto a pressure plate connected to the computer and a gender-matched avatar was then activated to cross the street. The avatar's walking speed in the VRPE matched children's walking speed, which was evaluated prior to the VPRE task in a separate location. If the avatar safely reached the other side, children heard 1 of 2 positive messages such as "Yes! Great job!" If the child made it across safely but was close to being hit by a car, the child heard, "Whoa! That was close!" If the child was struck by one of the cars, they heard, "Uh oh, you should try that again." Thus, the child was immersed into a virtual world while deciding when it was safe to cross. After choosing to cross, the world became third-person, and the child witnessed the safety (or danger) of the crossing. During the experimental visit, children performed 10 practice trials to reduce learning effects and then engaged in 12 virtual street crossings. Behavior in the 12 crossings was used for analysis.

Measures of Crossing Behavior

We considered 5 pedestrian outcome measures. First, we looked at overall risk of pedestrian injury, based on the count of hits/close calls children experienced over the 12 simulated

crossings. We also considered 4 aspects of crossing behavior: looking at traffic, wait time, latency to cross, and time to contact by an oncoming vehicle after entering a traffic gap.

Hits were any direct collisions between the virtual pedestrian and a vehicle. Close calls were instances when the pedestrian was within 1 second of being struck by a virtual vehicle. Simulated injury was operationally defined as having a collision/near collision with a virtual vehicle and was coded as a dichotomous variable (ie, whether or not participants had at least one simulated injury on any of the trials).

To evaluate attention to traffic, looks toward traffic were tallied by head-tracking equipment (Trackir4:Pro; NaturalPoint Inc, Corvallis, Oregon) that monitored participants' visual attention to traffic from the left and right. We summed the number of times participants looked left plus the number of times they looked right while waiting to cross, divided by the average wait time in seconds.

Wait time when crossing a street was defined as the amount of time children waited before entering the street. The outcome measured the latency between when the crossing trial was initiated and the moment the child stepped off the virtual curb. Shorter wait times may represent impulsive behavior patterns when crossing a street.[26]

The latency to start crossing was defined as the time elapsed, in milliseconds, between the last car passing through the crosswalk and the participant stepping off the curb to initiate crossing into the traffic gap. Unlike wait time, this measure assesses children's decision-making latency once a perceived safe gap appears. Prior research suggests this measure captures efficiency of the pedestrian decision making process, with more adept pedestrians having shorter latencies to enter traffic gaps.[10,11,26]

The time to contact by an oncoming vehicle was the shortest latency (in seconds) between the child and an oncoming vehicle during the time the child was in the crosswalk. Shorter time to contact by an oncoming vehicle indicates selection of a risky traffic gap to cross within.[26]

Data Analysis Plan

Following precedence from previous publications using the VRPE,[10,26-32] we first removed outliers ±2 SD from the mean of trials for each variable. These datapoints typically represented invalid data (ie, the child was distracted by conversation with the experimenter; experimenter error in running the VRPE). The following percentages of trials were removed for each variable: hits/close calls (0% of 1452 total trials [121 participants x 12 crossing trials]), looking at traffic (0%), wait time (4%), latency to start crossing (5%), and time to contact (3%).

Primary analyses were initiated with examination of descriptive statistics and evaluation of assumptions of inferential analyses. For the primary outcome of interest, the dichotomous hits/close calls variable, a mixed binomial logistic regression was used. For scaled demographic variables, groups were compared with paired sample *t* tests for normally distributed variables or nonparametric Wilcoxon signed rank tests for highly skewed variables. Next, linear mixed models with scaled identity covariance structure for residuals were conducted comparing the OSAS vs control groups on the pedestrian behavior outcome variables with the exception of wait time, which showed a non-normal distribution (Kolmogorov-Smirnov test, $P < .01$). In this case, a nonparametric Wilcoxon signed rank test was used. All analyses were conducted using SPSS, v 22 (IBM Corp, Armonk, New York). Significance was ascribed at $P < .05$.

Results

As expected based on recruitment of matched samples using a yoke-control procedure, there were no significant differences between groups in terms of age, race, sex, and household income (all *P*s > .10; see Table I). Also as expected, children with OSAS were sleepier than healthy controls (Wilcoxon signed rank test, $W(56) = 4.24$, $P < .0001$). The age- and sex-adjusted body mass index (BMI) of OSAS group (mean = 32.94, SD = 7.58) was significantly higher than that of control group (mean = 24.35, SD = 5.58), $t(53) = -6.71$, $P < .001$; there was also a significant difference in BMI z-scores (Wilcoxon signed rank test, $W(54) = 1378.5$, $P < .01$). Descriptive data for the OSAS children on overnight polysomnography are shown in Table II.

The primary hypothesis was that children with OSAS would have higher risk of pedestrian injury than the matched group of control children. A mixed binomial logistic regression comparing hits/close calls across groups found that children with OSAS had 2.2 greater odds of suffering simulated injuries (OR = 2.20, 95% CI = 1.01-4.80, Wald $\chi^2 = 3.91$, $P = .048$; Table III). Approximately 63% of children with OSAS were hit or had a close call compared with only 43% of the controls. To determine if there was a dose-response relationship between degree of sleepiness in OSAS and the

Table I. Demographic characteristics of children with OSAS and control group

Characteristics	OSAS (*N* = 60)	Control (*N* = 61)	χ^2 or paired *t*	*df*	*P*
Sex: % male	57	56	0.01	1	.918
Age: mean (SD), in y	12.61 (2.57)	12.94 (2.74)	0.66	59	.513
Ethnicity: African American/Caucasian/other (n)	42:16:2	44:17:0	2.07	2	.355
Household income, below $30 000/above $30 000 annual	31:29	25:36	1.39	1	.355
PDSS Total, mean (SD)	17.66 (6.78)	11.98 (4.89)	−4.96	55	<.001
BMI: mean (SD) (age- and sex-adjusted)	32.94 (7.58)	24.34 (5.58)	−6.75	53	<.001
BMI z-score	2.15 (0.86)	1.09 (0.99)	5.48*	54	<.001

*A Wilcoxon nonparametric test was performed for BMI z-score.

Table II. Characteristics of OSAS children (N = 60)

Characteristics	Mean	SD	Median	Range	IQR
Total sleep time, min	444.30	41.91			
Sleep efficiency	87.23	7.04			
Sleep latency, min	14.44	17.36	8.59	97.42	16.22
Arousals	23.43	11.04			
WASO, min	57.31	43.56			
Apnea hypopnea index	11.61	13.24	6.02	76.50	10.60

WASO, wake after sleep onset.

likelihood of injury, we dichotomized PDSS into two groups using a median split of 15 based on prior research.[25] A 2-way mixed binomial logistic regression analysis revealed a significant Diagnosis X PDSS interaction (Wald $\chi^2 = 6.07$, $P = .014$) such that approximately 76% of subjects with OSAS and high PDSS had a close call/hit compared with only 44% of controls with high PDSS.

To identify pedestrian behaviors that may contribute to the increased incidence of injuries among children with OSAS, we examined differences in the pedestrian behaviors of looking at traffic, wait time, latency to start crossing, and time to contact by an oncoming vehicle among children with OSAS vs the control group. As detailed in **Table III**, comparisons indicated a significant reduction in wait time among children with OSAS (OSAS mean = 11.95, SD = 6.93; control mean = 13.51, SD = 5.87; Wilcoxon signed rank test, $W(59) = -2.17$, $P < .30$), but no difference in latency to start crossing (OSAS mean = 1.19, SD = 0.45; control mean = 1.10, SD = 0.50; linear mixed model $F(1,117) = 1.07$, $P = .30$). The mean time to contact by an oncoming vehicle was 4.36 (SD 1.02) in patients with OSAS and 4.73 (SD 1.07) in controls (linear mixed model $F(1,117) = 3.82$, $P = .053$). Although this result failed to reach statistical significance, sensitivity analysis revealed a moderate effect size (f = 0.33; GPower 3.1.7). No differences were found between the groups in looking at traffic (OSAS mean = 32.29, SD = 11.88; control mean = 32.21; SD = 9.42; linear mixed model $F(1,116) = 0.002$, $P = .97$).

Discussion

Children with OSAS were more likely to get hit or nearly hit by a virtual vehicle than a control group of children matched using a yoke-control procedure by age, sex, race, and household income. This finding extends previous reports documenting the harmful effect of sleep deprivation on transportation safety of adults and adolescents.[13-15] In particular, this study offers initial evidence that untreated OSAS may be associated with increased injury risk to children in pedestrian settings.

We investigated additional aspects of pedestrian behavior in the virtual street environment by children with OSAS compared with the matched controls. Children with OSAS showed a pedestrian crossing pattern that implied dysregulation in the form of impulsivity. Children with OSAS waited less time before initially crossing a street compared with matched controls. As crossing the street requires the ability to wait for safe traffic gaps and to inhibit responses such as dashing into a street prior to safe gaps appear,[9,11] shorter wait times may represent impulsive behavior patterns when crossing the street.[26] This is consistent with the neurobehavioral profile reported in the pediatric OSAS literature,[33-36] once described as the "ADHD (attention deficit/hyperactivity disorder) conundrum."[36]

Interestingly, we did not find that looking at traffic or latency to start crossing were impaired among children with OSAS. A possible explanation for this finding is that when sleepy, children are able to follow simple and rote rules learned when they were young, such as looking both ways before crossing, but they may not fully process cognitively the complex environment they perceive. Others have reported fewer differences in looking behavior between impaired pedestrians and nonimpaired pedestrians than found on other aspects of pedestrian safety. This finding is consistent also with the pediatric sleep deprivation literature, which notes increased impulsivity and risk taking in both pediatric OSAS and sleep-deprived populations. For example, children with untreated OSAS have been described as having deficits in parallel to children with ADHD. In addition, children who are sleep deprived (similar to those with sleep disturbance from OSAS) have shown increased risk taking and impulsivity[37,38] Drawing a parallel, it appears children with untreated OSAS are similar to those with ADHD in that they "know what to do" (ie, look at traffic) but have difficulty implementing the rules, regulating behavior, or processing the information in the real world.[26]

The current findings have implications for both injury prevention and sleep medicine practice. Unintentional injuries are the leading cause of death in children under age 18.

Table III. Comparisons of pedestrian measures between children with OSAS and control group

Pedestrian risk outcome measures	OSAS	Control	χ^2	*df*	*P*
Hits/close calls (count)	37	26	4.48	1	<.034
	M (SD)	M (SD)	W or F	*df*	*P*
Looking at traffic (looks per min)	32.29 (11.88)	32.21 (9.42)	0.002*	1,116	.97
Wait time (s)	11.95 (6.93)	13.51 (5.87)	−2.17†	59	<.05
Latency to start crossing (decision-making time; s)	1.19 (0.45)	1.10 (0.50)	1.07*	1,117	.03
Time to contact by an oncoming vehicle (s)	4.36 (1.02)	4.73 (1.07)	3.82*	1,117	.05

M, mean; *W*, Wilcoxon.
*A linear mixed model was performed.
†A Wilcoxon nonparametric test was performed.

Identifying risk factors for injury, such as pediatric sleep disorders, is an important step to move toward development of prevention programs. In this particular case, we might consider 2 broad solutions: counseling about pedestrian injury risk by sleep professionals and increased community awareness to highlight the impact of sleepiness on children's pedestrian injury risk.

Within sleep medicine practice, these results reinforce the need for frequent screenings for symptoms of sleep disorders and heightened awareness of the daytime consequences of sleepiness and sleep disorders. Although many adolescents are cautioned about the effects of sleep deprivation and sleep disorders on motor vehicle crash risk, it appears that children with OSAS are at risk of injury—including pedestrian injury—well before they reach the age of driving. Injury risks from sleepiness should be discussed with pediatric patients complaining of sleep problems. Community interventions may also reduce risk. Such interventions could include road and traffic engineering to improve safety of children, including sleepy children, in street-crossing environments, safer "walking zones" near schools, and increased supervision of children with symptoms of OSAS in pedestrian settings by parents and school officials.

This study had limitations. First, we recruited children with OSAS from a clinically referred group of children. Children who are referred for testing may represent a group with more severe symptoms that prompt a referral than the larger community sample of children with OSAS. Second, while the sample met clinical threshold criteria for International Classification of Sleep Disorders Second Edition, and the group showed evidence of OSAS based on apnea hypopnea index scores, the sample as a whole had somewhat lower symptomatology than reported in some studies of children with OSAS. Third, our clinical sample of children with OSAS was evaluated the morning after their diagnostic NPSG. There is some evidence of a "first night" effect for children undergoing polysomnography that might contribute to daytime sleepiness.[39,40] However, the children with OSAS in our sample slept well during the overnight routine sleep study. Overall sleep efficiency, defined as time in bed vs time asleep, was quite high at 87% and within the normative range.[41] Fourth, our sample of children with OSAS had a significantly higher age- and sex-adjusted BMI than the control group. This is not surprising given relations between obesity and OSAS,[20] and post-hoc analysis of BMI as a covariate in regression models indicated BMI was not associated with any of our outcome measures. Fifth, although we did screen for OSAS in healthy controls by asking parents if the child had a known sleep disorder, and the control group had a significantly lower sleepiness rating on the PDSS than the children with OSAS, it is possible that children in the control group could have had undiagnosed OSAS. If this was the case, it would have attenuated rather than inflated our findings.

Pedestrian behavior is multifaceted. The virtual reality environment evaluates pedestrian behavior at a mid-block crossing. We did not investigate pedestrian behavior at signalized crossings, patterns of route selections when more than one crossing option is available, or perception of acceleration/deceleration in vehicles, for example. Findings are limited to pedestrian injury, and the effect of OSAS on playground behavior, sports injuries, and other potentially risky situations was not examined understood. Future research is needed to identify other aspects of injury risk in children with OSAS, treatments that reduce injury risk in children, and possible countermeasures that may be implemented to promote increased safety. Future research might also consider whether treatments for OSAS successfully reduce injury risk. ■

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